NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 517

FLIGHT INVESTIGATION OF LATERAL CONTROL DEVICES FOR USE WITH FULL-SPAN FLAPS

By H. A. SOULÉ and W. H. McAVOY

1935

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AERONAUTIC SYMBOLS

1. FUNDAMENTAL AND DERIVED UNITS

	Symbol	Metric		English	
		Unit	Abbreviation	Unit	Abbreviation
Length	l	meter	m	foot (or mile)	ft. (or mi.)
Time	t	second	s	second (or hour)	sec. (or hr.)
Force	F	weight of 1 kilogram	kg	weight of 1 pound	lb.
Power	P	horsepower (metric)		horsepower	hp.
Speed	V	kilometers per hour	k.p.h.	miles per hour	m.p.h.
		meters per second	m.p.s.	feet per second	f.p.s.

2. GENERAL SYMBOLS

W, Weight $= mg$

g, Standard acceleration of gravity $= 9.80665$ m/s^2 or 32.1740 ft./sec.^{2}

m, Mass $= \frac{W}{g}$

I, Moment of inertia $= mk^2$. (Indicate axis of radius of gyration k by proper subscript.)

μ, Coefficient of viscosity

ν, Kinematic viscosity

ρ, Density (mass per unit volume)

Standard density of dry air, 0.12497 kg-m^{-4}-s^2 at 15° C. and 760 mm; or 0.002378 lb.-ft.$^{-4}$ sec.^{2}

Specific weight of "standard" air, 1.2255 kg/m^3 or 0.07651 lb./cu.ft.

3. AERODYNAMIC SYMBOLS

S, Area

S_w, Area of wing

G, Gap

b, Span

c, Chord

$\frac{b^2}{S}$, Aspect ratio

V, True air speed

q, Dynamic pressure $= \frac{1}{2}\rho V^2$

L, Lift, absolute coefficient $C_L = \frac{L}{qS}$

D, Drag, absolute coefficient $C_D = \frac{D}{qS}$

D_o, Profile drag, absolute coefficient $C_{D_o} = \frac{D_o}{qS}$

D_i, Induced drag, absolute coefficient $C_{D_i} = \frac{D_i}{qS}$

D_p, Parasite drag, absolute coefficient $C_{D_p} = \frac{D_p}{qS}$

C, Cross-wind force, absolute coefficient $C_C = \frac{C}{qS}$

R, Resultant force

i_w, Angle of setting of wings (relative to thrust line)

i_t, Angle of stabilizer setting (relative to thrust line)

Q, Resultant moment

Ω, Resultant angular velocity

$\rho\frac{Vl}{\mu}$, Reynolds Number, where l is a linear dimension (e.g., for a model airfoil 3 in. chord, 100 m.p.h. normal pressure at 15° C., the corresponding number is 234,000; or for a model of 10 cm chord, 40 m.p.s. the corresponding number is 274,000)

C_p, Center-of-pressure coefficient (ratio of distance of *c.p.* from leading edge to chord length)

α, Angle of attack

ϵ, Angle of downwash

α_o, Angle of attack, infinite aspect ratio

α_i, Angle of attack, induced

α_a, Angle of attack, absolute (measured from zero-lift position)

γ, Flight-path angle

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By H. A. Soulé and W. H. McAvoy

SUMMARY

Flight tests were made of five different lateral control devices that appeared adaptable to wings fitted with full-span flaps: Controllable auxiliary airfoils (airfoils mounted above and forward of the leading edge of the wings), external ailerons (airfoils mounted above the wing and slightly forward of its maximum ordinate), upper-surface ailerons (similar to split trailing-edge flaps except that they constitute the upper surface of the wing), ailerons that retract into the wing when in neutral, and narrow-chord conventional ailerons in combination with a special type of split flap that retracts into the under surface of the wing forward of the ailerons. The devices were tested on a small parasol monoplane.

Only the retractable ailerons and the narrow-chord ailerons in combination with the special split flap were found to be satisfactory. The absence of appreciable aerodynamic hinge moments of the retractable ailerons was considered to be somewhat objectionable but this characteristic can probably be remedied by a slight modification. The external ailerons were unsatisfactory in the normal-flight range because of an irregular variation of their hinge moments with deflection and a relatively weak rolling action. These ailerons are believed to warrant further development, however, because they retain their effectiveness above the stall. The controllable auxiliary airfoils had lag as well as excessive hinge moments and hence appear to warrant no further development. The upper surface ailerons had excessive hinge moments but were otherwise satisfactory.

Experience gained in the use of flaps during these tests has indicated the desirability of a flap that can be operated quickly and easily.

INTRODUCTION

The National Advisory Committee for Aeronautics is conducting an investigation in wind tunnels and in flight for the purpose of improving the lateral control of airplanes. In the wind-tunnel investigation, the results of which are reported in reference 1, a comparison has been made of various lateral control devices with particular reference to conditions at high angles of attack where conventional ailerons were known to give unsatisfactory control. The first series of flight tests (reference 2) were made to check the wind-tunnel data on several of the more promising devices.

In connection with the split flap, which is now coming into general use as a means of decreasing the landing speed and increasing the gliding angle at landing, it has been shown (reference 3) that by the present practice of installing the flap over only the section of wing between conventional ailerons, the full potential value of the flap is not realized. An appreciable reduction in the minimum flying speed of the airplane would be obtained if the conventional ailerons were replaced by some lateral control device permitting the use of a full-span flap. Mr. Zaparka, by employing external ailerons above the rear of the wing, has already demonstrated one means of accomplishing lateral control with full-span flaps. During the wind-tunnel tests of reference 1, several other control devices that were adaptable to wings with a full-span flap were tried. Of these the controllable auxiliary airfoil (fig. 1 (a)), the external aileron mounted above the wing near the maximum ordinate (reference 1, pt. XIII) (fig. 1 (b)), and the upper-surface aileron (reference 1, pt. XII) (fig. 1 (c)) showed sufficient promise to warrant testing them in flight. The present paper deals with the results of flight tests of these lateral control systems. In addition, there are also reported tests of two lateral control systems intended primarily to replace the conventional aileron control system and permit the installation of full-span flaps; they were not expected to give control above the stalling angle. One of these control systems consisted of retractable ailerons (fig. 1 (d)) similar in form to the retractable spoilers of reference 2 but situated near the trailing edge of the wing to act somewhat in the manner of the upper-surface ailerons. The other consisted of a combination of very narrow-chord conventional flap-type ailerons and a special type of split flap (fig. 2) that retracted forward of the ailerons similar in manner to the movement of the Zap flap. The motion of the flap was so arranged that in no position did the flap interfere with the operation of the ailerons.

The flight tests were made in two parts. The first part consisted of tests, similar to those in reference 2, in which the pilots recorded their impressions of the

effectiveness of each lateral control device in a series of standard maneuvers. The completeness with which these tests were made depended on the findings on the first flight. The second part of the tests were made only with the retractable ailerons and the combination of narrow-chord ailerons and special flap, the only control systems found to warrant additional tests. In the more complete tests, instrument measurements were made of the lag characteristics and of the

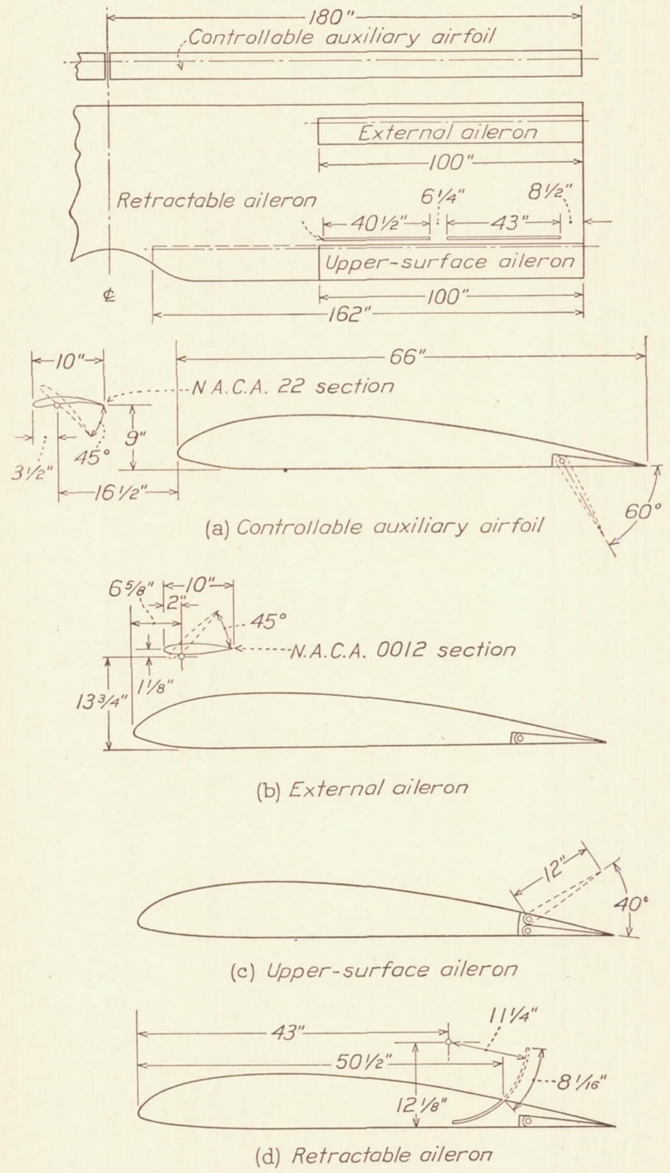

FIGURE 1.—Lay-out of special wing equipped with plain split flap, controllable auxiliary airfoil aileron, external aileron, upper-surface aileron, and retractable aileron.

rolling and yawing action of the control devices. These values were compared with similar results obtained with the standard ailerons of the Fairchild 22 airplane, the airplane on which the various lateral control devices were mounted for the tests.

APPARATUS

The investigation was conducted with 2 Fairchild 22 airplanes and 3 wings for these airplanes, the standard wing and 2 special wings incorporating full-span flaps and the special control devices. The Fairchild 22 is a small light parasol monoplane shown in the photograph in figure 3 and by a three-view diagram in figure 4. The standard wing and control system for the airplane are shown in figure 5. The wing has an N–22 airfoil section, circular tips, and an area of 172 square feet. It is installed on the airplane with an angle of wing setting of 1° and a dihedral angle of ½°. The unbalanced ailerons have a chord of 18 percent of the wing chord and are practically full span (83 percent $b/2$), extending from just inboard of the circular tips to the center-section cut-out of the trailing edge. They are operated with a differential motion having an up deflection of 19° and a down deflection of 8°.

One special wing (fig. 1) was of the same section and approximately the same lay-out as the standard wing with the exception that this wing was constructed

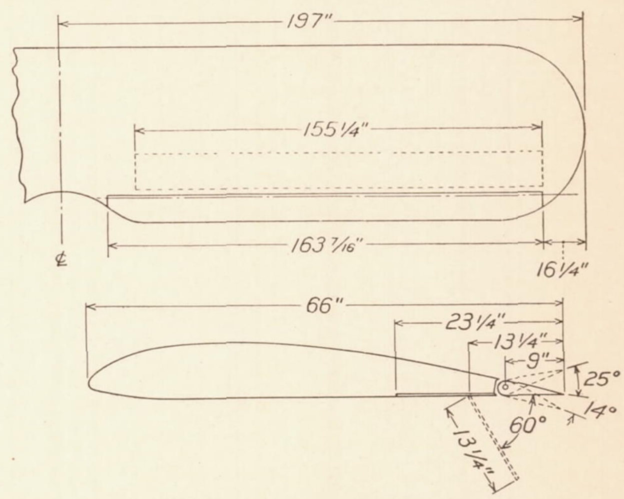

FIGURE 2.—Lay-out of special wing equipped with split flap retracting forward of narrow conventional ailerons.

with square tips more closely to approximate the model used in the wind-tunnel tests of reference 1. Its area was 161 square feet. The wing was installed on the airplane with the same angle of wing setting as the standard wing but with 3° dihedral. It was equipped with plain split flaps (fig. 1) extending from the tips to the center-section cut-out (90 percent $b/2$). Their chord was 20 percent of the wing chord and their maximum deflection 60°. Originally three independent lateral control systems were incorporated in the wing: The controllable auxiliary airfoils, the external ailerons, and the upper-surface ailerons. During the course of the investigation the wing was modified and the retractable ailerons were added.

The controllable auxiliary airfoils (fig. 1 (a)) were of the N. A. C. A. 22 section and were installed with their trailing edges, when neutral, 15.2 percent c (where c is the chord of the main wing) forward of the leading edge of the wing and 13.6 percent c above the chord of the wing. In the neutral position their chord lines

were parallel to that of the wing. Each airfoil had a chord of 15.2 percent *c* and extended over the semispan of the wing. This arrangement was found in reference 4 to give the greatest increase in performance; consequently, in the present installation the airfoils functioned as a high-lift as well as a lateral control device. For the purpose of lateral control the airfoils were hinged at a point 35 percent of their chord back of their leading edge and 2.8 percent of their chord below their chord line. The operating mechanism was so arranged that the right airfoil rotated trailing edge down through an angle of 45° when the control column was moved to the right, while the left airfoil remained stationary. For a left movement of the control column, only the left airfoil was moved.

The external ailerons (fig. 1 (b)) were symmetrical airfoils having the N. A. C. A. 0012 section. Their hinge axes were located 10 percent *c* aft of the leading edge and 20.8 percent *c* above the chord of the wing. Each aileron was located with its leading edge 20 percent of the aileron chord ahead and its chord line 11.2 percent of the aileron chord above the aileron hinge axis. The ailerons extended 55.5 percent $b/2$ inboard of the wing tips and had a chord of 15.2 percent of the wing chord. When neutral the aileron chord was parallel to the main wing chord. As with the controllable auxiliary airfoils, the control mechanism was arranged to operate only one aileron at a time. Through an adjustment of the linkage, the ailerons could be given either a rotation of trailing edge up 45° or trailing edge down 45°.

The upper-surface ailerons (fig. 1 (c)) had spans 55.5 percent $b/2$ and chords 18.2 percent *c*. They were operated up-only with a maximum deflection of 40°. As the upper-surface ailerons most nearly approached the conventional ailerons, means were provided whereby these could be operated as a safety device through an independent control system with an auxiliary control stick during the preliminary flights of the controllable auxiliary airfoils and the external ailerons.

The retractable ailerons (fig. 1 (d)) were developed during the tests to replace the upper-surface ailerons when it became apparent that the latter were unsatisfactory because of the high operating forces required. Each aileron consists of a curved plate normally enclosed in the wing with its upper edge flush with the upper surface of the wing. For control the aileron on the wing that is to be depressed is rotated out of the wing about an axis coincident with the center of curvature of the plate. As the principal aerodynamic forces on the plate act normal to the surface, the aerodynamic hinge moment is negligible. The difference between the retractable ailerons and the retractable spoilers of reference 2 is in their location on the wing surface, the retractable ailerons being located on the after part of the wing in a position approximating that for the hinge line of the upper-surface ailerons; whereas the retractable spoilers are located ahead of the maximum ordinate of the wing.

The hinge axis of the retractable ailerons was 65 percent *c* aft of the leading edge and 18.4 percent *c* above the chord of the wing. The slots through which the ailerons projected were located 76.5 percent *c* aft of the leading edge of the wing. The over-all span of each aileron was 50 percent $b/2$. Because of interference with a principal structural member, each aileron was made in two sections. At full deflection the ailerons projected 12 percent *c* above the surface of the wing. For reasons which will be discussed later, these ailerons were operated with an extreme differential motion instead of up-only, despite the fact that the motion of the down-going aileron was entirely within the wing.

The second special wing (fig. 2) had the same plan form as the standard wing but had the N. A. C. A. 2412 airfoil section. This wing was installed on the airplane with a dihedral angle of ½° and an angle of wing setting of 4½°, an angle which gave the same angle of thrust line for zero lift as did the standard wing. The features of this wing were a special flap having a span of 78.9 percent of the wing span and a chord of 20 percent of the wing coord, which when fully deflected was in the same position relative to the wing as the plain split flap on the first special wing. This flap, however, retracted upward and forward into the wing in a manner similar to that used in the Zap flap so that it would not interfere with the operation of a very narrow-chord aileron of the conventional flap type. The aileron had the same span as the standard aileron but a chord of only 13.6 percent of the wing chord. In order to compensate for its smaller chord the aileron was given larger deflections (up 25° and down 14°) than the standard ailerons.

TESTS

In accordance with established practice followed with new types of lateral control systems, all the devices reported in this paper were tried out in the full-scale wind tunnel before they were used in flight tests. The wind-tunnel runs are made to eliminate some of the danger of the preliminary flights by giving the pilots an opportunity to become somewhat familiar with the operating characteristics of the different control systems at an air speed corresponding to the speed of flight. Usually no measurements are made and the results of the tests are not reported. In the present case, however, note is made of the tunnel work because tests were made while the airplane was in the tunnel to obtain an indication of the lag characteristics of the control systems in which the control surfaces were mounted on the forward portion of the wing. The results of these tests are included with the flight results.

The flight-test work consisted of preliminary flights to uncover any radical differences in the operation of the various control systems from that of conventional

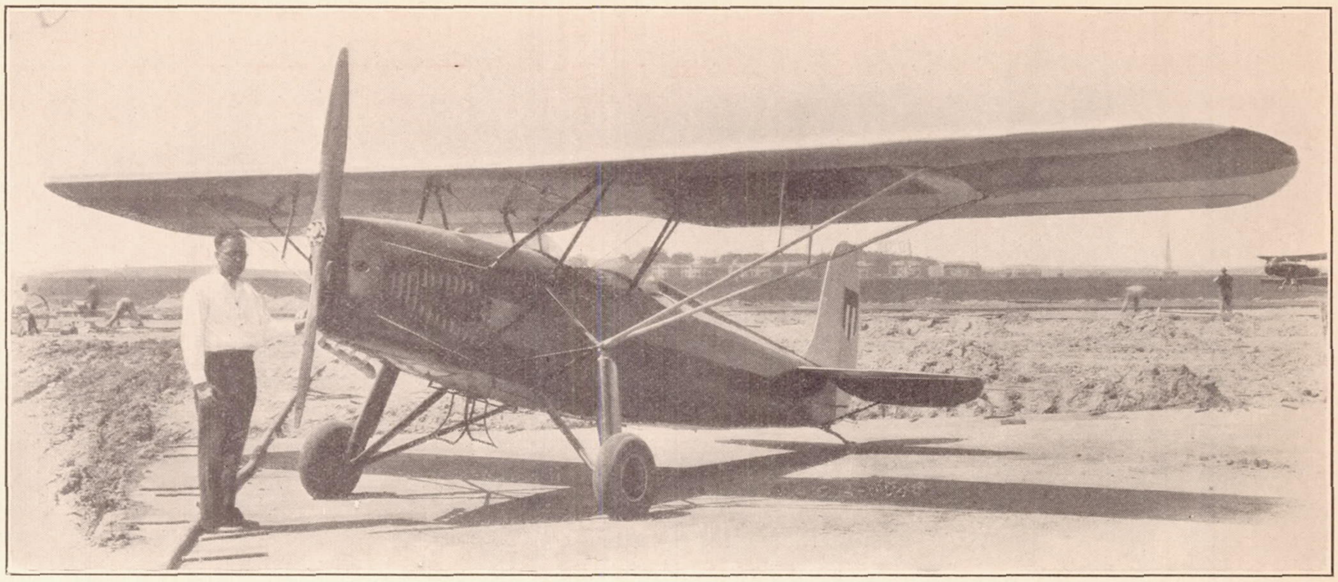

FIGURE 3.—Fairchild 22 airplane.

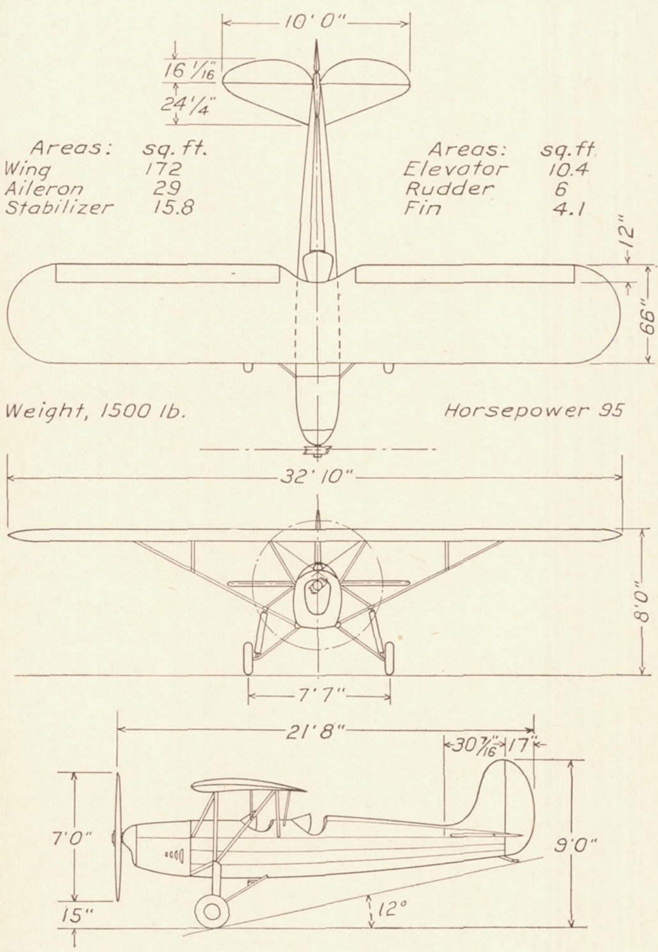

FIGURE 4.—Three-view drawing of the Fairchild 22 airplane.

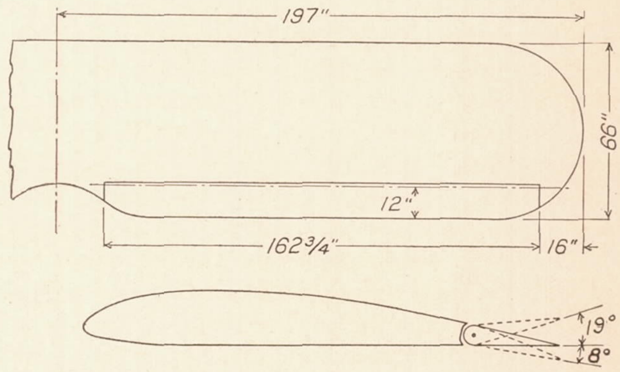

FIGURE 5.—Lay-out of standard Fairchild 22 wing and aileron installation.

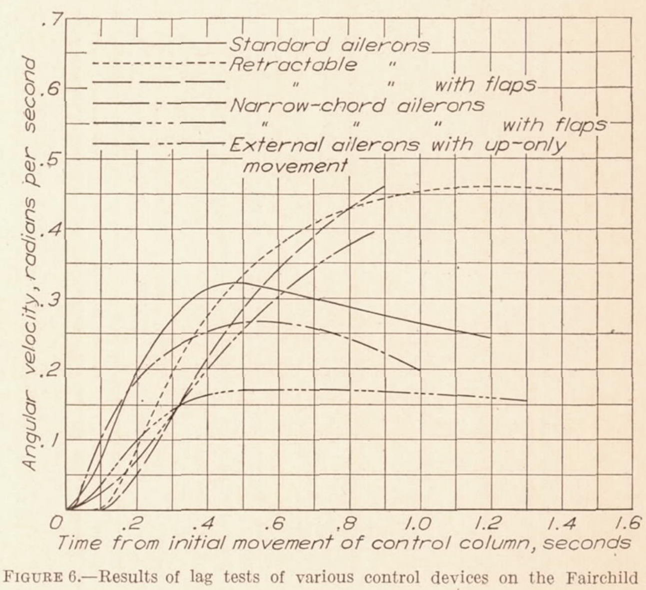

FIGURE 6.—Results of lag tests of various control devices on the Fairchild 22 airplane.

ailerons, of observation flights in which the pilots observed the control action for a series of standard maneuvers, and of instrument flights during which the lag and the rolling and yawing action were measured. The extent to which the tests were completed with each control system depended on the findings of the preliminary flights. Thus, only the preliminary flights were made with the controllable auxiliary airfoils and external ailerons with down-only motion; whereas the complete series of tests was carried out on the retractable ailerons and the very narrow-chord ailerons. For purposes of comparison, the tests were also conducted with the standard wing and ailerons for the Fairchild 22 airplane.

The tests in which the results depended on the pilot's observations alone were performed independently by two pilots. In these tests the airplane was put through a standard series of maneuvers designed to show qualitatively the effectiveness of each device in producing lateral control and its effect on the stability of the airplane, the pilots making notes at the time of the tests on special forms provided for the purpose.

For the instrument flights, 2 angular velocity recorders (1 to record the rolling action and 1 the yawing action), an instrument to record the lateral position of the control column, an air-speed recorder, and a timer were installed in the airplane. The procedure followed in the tests was to record the motion of the airplane for a short period immediately following an abrupt right displacement of the control column from neutral during steady gliding flight. In order to determine whether or not the control action of the devices tested was approximately proportional to the control displacement and whether or not comparisons could be made on the basis of the action at full deflection, a series of runs was first made at a constant air speed in which the control action for several intermediate stick deflections as well as for full deflection were recorded. The control action for full deflection was then measured at several air speeds covering the lower portion of the speed range where most difficulty is met in obtaining satisfactory lateral control.

RESULTS

Reduction of instrument data.—Lag in the control action was determined as the time between the initial movement of the control column and the start of the rolling action in the desired direction. The lag for the retractable ailerons may be noted in figure 6, which gives sample time histories of the rolling velocity for the different devices and shows the general character of the response obtained with each device at a speed slightly above the stalling speed for the given wing arrangement. Because of the different air speeds of the tests and the different moments of inertia of the wings used, no direct comparisons should be made between the curves of the figure.

An inspection was made of the record of the yawing velocity to determine the sign of the yawing action relative to the Z body axis.

The record of the rolling velocity was first graphically differentiated to determine the maximum angular acceleration in roll. As the records showed that the airplane acquired an appreciable rolling velocity while the lateral control surface was being fully deflected, it was apparent that the moment which could be computed directly from this acceleration would not correspond to the moments obtained from wind-tunnel tests where the model is held rigidly and not permitted to roll. In an attempt to make the flight data comparable with wind-tunnel data, the acceleration was corrected to zero rate of roll. In order to make this correction, the maximum angular velocity and the angular velocity at the instant of maximum angular acceleration were then determined. The assumption was made that the resultant rolling moment is composed of a moment resulting from the control deflection independent of the rate of roll and a damping moment varying directly with the rate of roll and that at the maximum rate of roll these two moments are of equal magnitude. On this basis the approximate acceleration for zero rate of roll was then found by means of the equation

$$\left(\frac{dp}{dt}\right)_0=\left(\frac{dp}{dt}\right)_{rec}\left(\frac{p_{max}}{p_{max}-p_{rec}}\right)$$

where $\left(\frac{dp}{dt}\right)_0$ is the acceleration that would be induced by the lateral control device at zero rate of roll.

$\left(\frac{dp}{dt}\right)_{rec}$, the maximum acceleration recorded.

p_{max}, the maximum rolling velocity.

p_{rec}, the rolling velocity at time of maximum acceleration.

For the devices tested the information thus obtained is given as a function of the air speed at the time of the control deflection. (See figs. 7 to 9.) Rolling-moment coefficients were computed by the formula

$$C_l=\frac{\left(\frac{dp}{dt}\right)_0 A}{qbs}$$

where A is the moment of inertia about the X body axis and, for the airplane with the standard ailerons installed, is 696 slug feet^2, for the retractable ailerons 1,294 slug feet^2, and for the narrow ailerons 1,061 slug feet.^{2} The rolling-moment coefficients are plotted in figure 10 as a function of the lift coefficient. The lift coefficient was computed by the equation

$$C_L=\frac{W}{qS}$$

The weights W with the standard ailerons, the retractable ailerons, and the narrow-chord ailerons were 1,494 pounds, 1,654 pounds, and 1,585 pounds, re-

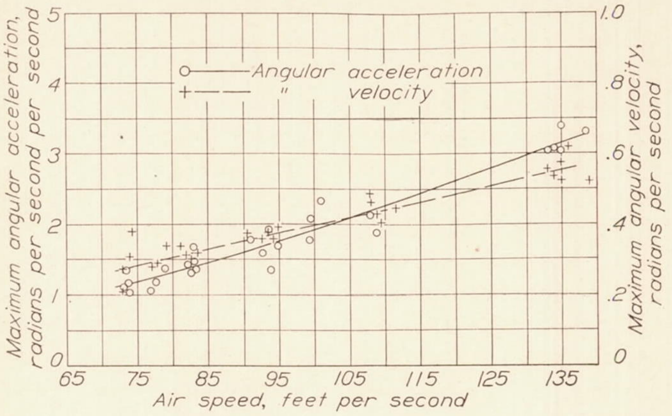

FIGURE 7.—Variation of maximum angular velocity and acceleration with air speed for standard ailerons.

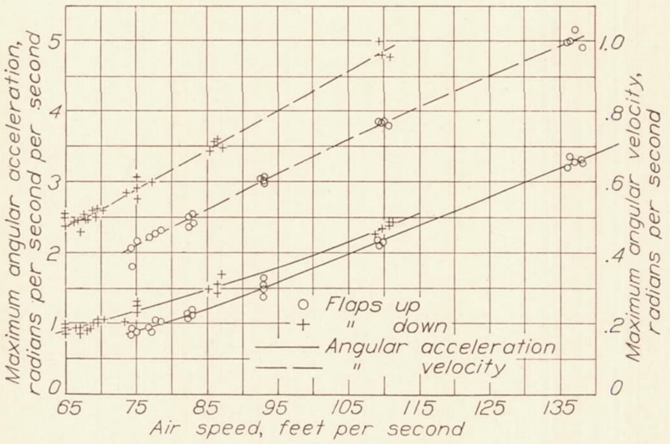

FIGURE 8.—Variation of maximum angular velocity and acceleration with air speed for retractable ailerons.

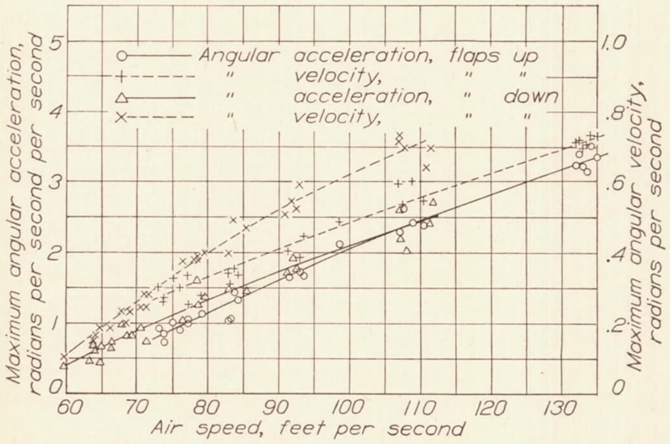

FIGURE 9.—Variation of maximum angular velocity and acceleration with air speed for narrow-chord ailerons.

spectively. The rolling criterion $\frac{C_l}{C_L}$ is shown in figure 11.

Desirable characteristics of a lateral control system.—As the characteristics of each lateral control system in the present tests have been considered relative to the desirable characteristics of a lateral control system as discussed in reference 2, the following résumé of that discussion has been inserted in this paper.

There should be no lag in the rolling action of a lateral control system; that is, there should be no apparent time lapse between the control-surface movement and the start of the rolling motion in the desired direction. The rolling action should also be proportional to the movement of the control stick. The rolling moment,

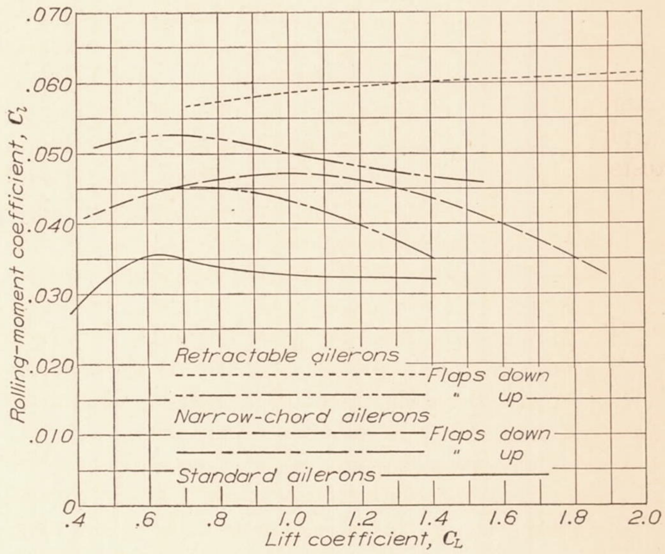

FIGURE 10.—Variation of C_l with C_L for standard, retractable, and narrow-chord ailerons.

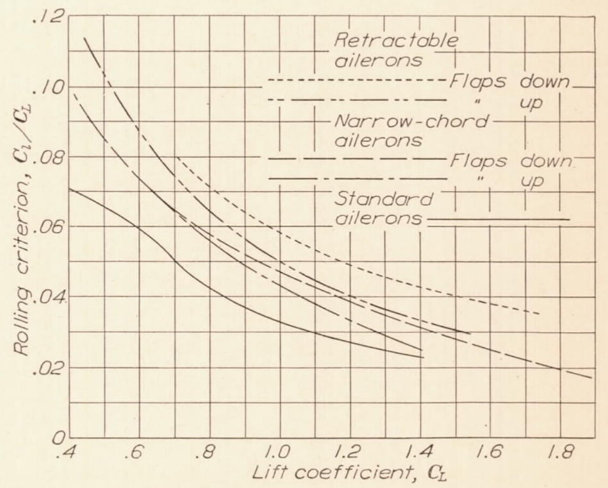

FIGURE 11.—Comparative curves of rolling-moment criterion for standard, retractable, and narrow-chord ailerons.

one of the two elements constituting the rolling action, should be as large as possible. It is limited only by structural considerations and the possible discomfort that the acceleration produced by it may cause the occupants of the airplane. The maximum rolling velocity, the other element of the rolling action, should also be large, but with this characteristic there is apparently an upper useful limit which the pilots are not likely to exceed even if higher rates of roll are available.

The yawing action should be zero but small yawing moments of either sign cause no appreciable difficulty in the normal-flight range. Beyond the stall, however, it is better that the yawing action be positive rather than negative.

The stick force should be as light as possible consistent with the feel of a definite neutral point and a progressive increase of force as the stick is displaced from neutral.

Standard ailerons.—The standard ailerons are considered by the pilots to be representative of conventional lateral control systems. The pilots reported that the ailerons were light in operation and gave immediate response and good rolling action up to the stall. At angles of attack above the stall, however, the ailerons were found to be unsatisfactory. When the ailerons were applied in this range, the airplane might or might not roll in the desired direction and the ailerons would not reverse a stalled turn after it was once started. The yawing action was negative and fairly large. Below the stall the adverse yaw, although apparent, caused no great annoyance, at least to experienced pilots. Above the stall, however, it probably accounted for the lack of ability to reverse stalled turns.

The pilots' observations concerning the lag and yawing action were substantiated by the instrument measurements. A control movement caused immediate response in roll (fig. 6). The recorded yawing action about the body axis was negative; therefore, it must have been negative about the wind axis.

The rolling-moment coefficient for these ailerons was found to be practically constant over the speed range tested and had an average value of approximately 0.032. As a result the rolling criterion (fig. 11) fell off rapidly with increasing lift coefficient from a value of 0.062 at a lift coefficient of 0.30 to 0.02 at the stall. The maximum rate of roll (fig. 7) obtained with the ailerons varied almost linearly with speed from 0.55 radian per second at 135 feet per second to 0.28 radian per second at 75 feet per second.

Controllable auxiliary airfoils.—The tests in the full-scale tunnel indicated that the controllable auxiliary airfoils would probably have lag and that the stick forces required to operate them would be excessive. In flight the pilot found it nearly impossible to move the control stick from neutral even at low speeds because of the high stick forces. No check could therefore be made on the lag. As the tests with other control systems have shown that the conclusions drawn from the full-scale tunnel tests regarding lag were reliable, no attempt was made to improve the stick forces by relocating the hinge axis. This control system was discarded after the preliminary flights.

External ailerons.—The tests in the full-scale wind tunnel had indicated that with the down-only movement the external ailerons would have lag. Flight tests were carried only to the point where the lag was found to be present.

The only instrument tests made with the external ailerons with up-only movement were those to show the general character of the response to control displacement and to prove that the system had no lag. The rolling action was observed by the pilots to be weak at all speeds and practically constant throughout the flight range. In this respect the action differed from that for normal ailerons for which the rolling action increases with air speed. Neither was the rolling action proportional to the stick deflection. The controls gave only a very slight response until approximately half of the full deflection was attained. The yawing action was slightly positive and the control system did give a fair amount of control beyond the stall. The principal objection to the control system was the stick force required, which was very heavy and not proportional to the deflection. The force was high for the initial movement of the stick and increased with deflection through the first half of the range. With further deflection the stick force decreased noticeably over a portion of the range but increased again as full deflection was approached.

Modifications consisting of shifting the hinge axis of these ailerons first to their 22½ percent chord point and then to their 25 percent chord point were tried in an attempt to improve the stick force. These changes did not affect the rolling and yawing action sufficiently to be noticed by the pilots. The stick force, however, was reduced but the manner in which the force varied with deflection was not changed. At the rearmost position of the hinge axis, the average stick force was still quite heavy, but at the point where the stick force was lowest, just beyond the one-half deflection point, the force became approximately zero. Further rearward positions of the axis were not tried because of the probability of overbalance at this deflection. As the lateral control with the external ailerons was not satisfactory with flaps up, no tests were made with the flaps down.

Upper-surface ailerons.—With the upper-surface ailerons the control characteristics with the exception of the hinge moment were much the same as with the normal ailerons. The rolling action was satisfactory with flaps either up or down, up to but not beyond the stall. The yawing action was slightly adverse with flaps up and definitely adverse with flaps down. It seems peculiar that changing the form of a wing tip by raising the aileron should reduce the drag on that side of the wing but this finding is in agreement with the results of the wind-tunnel tests on the upper-surface aileron. Evidently the induced drag is reduced by a greater amount than the profile drag is increased.

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The stick forces were excessive with the upper-surface ailerons. It was impossible fully to deflect the controls at any but low speeds. In an attempt to improve the control action so as to obtain a better indication of the control effectiveness from the pilots' standpoint, a mechanical balance was applied to the control system. The balance, which was unsuitable for permanent use, consisted of springs that applied an increasingly greater moment against the aerodynamic moment as the control was deflected from the neutral position. On the ground with the weight of the up aileron acting against the balance, a 10-pound pull on the control column was required to return the aileron to neutral from the fully deflected position. Some indication of the magnitude of the aerodynamic forces acting on the control system in the normal-flight range can be obtained from the fact that at an air speed of 25 miles per hour during the taxi run the air forces were sufficient to return the up aileron to neutral against the spring system. With the exception of stick forces, the control was apparently satisfactory and, as the result of a study made to reduce the stick forces, the retractable ailerons were developed.

Retractable ailerons.—The retractable ailerons, as expected, had about the same characteristics as the upper-surface ailerons with the exception of the required stick force. The pilots considered the rolling action slightly improved and noted that with flaps up the yawing action was approximately zero. With flaps down, however, the yawing action was negative, although less than for the upper-surface ailerons. The required control-stick force was the same in the air as on the ground, the only appreciable hinge moment being that resulting from the weight of the control surfaces. The stick forces for this control system were considered by the pilots to represent the opposite extreme from those for the controllable auxiliary airfoils. The stick was so light as to have no "feel", particularly near neutral where the mechanical advantage for the two control surfaces was approximately equal and their weight moments tended to balance. No lag in the rolling action was noticed by the pilots. Except for the stick-force characteristics the pilots considered the retractable ailerons to be better than the standard ailerons.

The instrument records (see fig. 6) showed the retractable ailerons to have a lag of about 0.10 second. Apparently this amount of lag is not noticeable to the pilots. The maximum accelerations obtained with the retractable ailerons with flaps up were slightly less than with the standard ailerons at comparable speeds. The maximum angular velocities, however, were much higher, in the order of one and one-half times as great. These apparently contradictory results are explained by a greater moment of inertia for the wing in which the retractable ailerons were installed, the effect of the greater moment of inertia being to decrease the angular acceleration for a given rolling moment without changing the maximum angular velocity. The rolling-moment coefficients and rolling criterions were actually greater with the retractable ailerons by amounts corresponding to the greater maximum angular velocities.

Both the rolling velocity and acceleration were increased at a given air speed by lowering the flaps. A fairly high value of the rolling-moment coefficient (0.060) was maintained up to the stall of the airplane with the flaps down, although the maximum acceleration at the stall was less with the flaps down than up, because of the lower speeds with the flaps down. The rolling criterion, which is dependent on the rolling-moment coefficient, was greater with the flaps down at the same values of the lift coefficient.

The records of yawing action indicated that with the flaps up the retractable ailerons had a positive yawing moment and with flaps down, zero yawing moment. The records may, at first, appear to be in disagreement with the pilots' reports that the yawing action was zero with flaps up and negative with flaps down but this seeming disagreement can be readily explained from the fact that the instruments recorded the yawing action about the body Z axes; whereas the pilots observe the action about an axis more nearly in line with the wind Z axis (reference 2). Evidently in the present case the resultant rotation with the flaps up took place about the wind X axis and consequently had no component about the wind Z axes although a positive one about the body Z axes. With the flaps down the resultant rotation was about the body X axis and had a negative component about the wind Z axes, which the pilots observed.

Narrow-chord ailerons.—According to wind-tunnel tests, the narrow-chord ailerons should have given approximately the same control characteristics as the standard ailerons, the smaller chord being compensated for by the greater deflections. The pilots' observations indicated that such was the case. As with other trailing-edge controls, the narrow-chord ailerons were unsatisfactory above the stall. These ailerons, as expected, gave adverse yaw both with flaps up and down. The stick forces were the most satisfactory of all the control systems tested. They were lighter than the normal ailerons but sufficiently heavier than the retractable ailerons to give the desired feel to the stick.

The instrument records indicated that the rolling action was a little better than that for the standard wing. The maximum rolling velocity was slightly greater but was less than with the retractable ailerons. The rolling-moment coefficients and the rolling criterions also were somewhat greater than for the standard ailerons, although less than for the retractable. The records indicated that the adverse yaw was smaller with the flaps down than up. The yawing action with

the flaps down was, in fact, comparable with that for the retractable ailerons with flaps down.

DISCUSSION

Although with the present installation it was impossible to determine the rolling and yawing action of controllable auxiliary airfoils because of the high stick forces required to move the airfoils, the auxiliary airfoils appear to offer very little promise for development into a satisfactory combination high-lift and lateral control device. The hinge moments might have been reduced and a satisfactory value obtained by relocating the airfoil hinge axis as was done with the external ailerons, but this procedure did not seem desirable in view of the lag exhibited by the control system. The occurrence of the lag is a serious matter and in this case is probably greater than that obtained with a plain spoiler control because the airfoils are rotated in a direction to increase the lift on themselves while spoiling the flow over the main wing. The possibility of rotating the airfoils in the opposite direction has been considered, but the tests of reference 1, part X, show that adequate control is not likely to be obtained throughout the complete flying range if the airfoils are rotated trailing edge up.

The external ailerons with down-only movement similar to the controllable auxiliary airfoils are likely not to be susceptible to further development because of lag. With up-only movement, however, they have chance of development, particularly in view of the fact that they gave a fair degree of control beyond the stalling angle. There is also the likelihood, as shown by reference 1, part XIII, that they increase the lateral stability of the airplane at the higher angles of attack, although this increase was not noted during the flight tests. Several lines of development might be followed. It might be possible to find an airfoil section whose center-of-pressure characteristics are more adaptable to use as external ailerons than the N. A. C. A. 0012 section now employed, and by this means a linear variation of hinge moment with deflection might be obtained. The problem of obtaining moments of reasonable magnitude would then simply be one of correctly locating the hinge axis. The external ailerons in the present installation are set when in neutral at the angle found to give the greatest lift. Consequently a movement of an aileron in either direction decreases the lift on that wing and it is therefore necessary that only one aileron be operated at a time. Were the neutral angle chosen to give less than the maximum lift possible, the ailerons could be operated through a normal differential linkage and the hinge moments would probably be improved.

The problem of obtaining satisfactory stick forces for lateral control systems in which the control surface on only one wing is moved at a time, such as the controllable auxiliary airfoils, the external ailerons, and the upper-surface ailerons, is always likely to be more difficult than for conventional ailerons. In the case of conventional ailerons, the surfaces on the opposite wings are interconnected and hinge moments of the same sign and magnitude balance. Consequently, at the neutral position the sign and magnitude of the hinge moments of the individual ailerons are of no significance, except possibly where the span loading is unsymmetrical as during a sideslip. It is only required that the change of moment when the ailerons are deflected be of small magnitude and that the sign of the change be such as to return the control stick to neutral. Where only one control surface is moved at a time, however, the surfaces cannot be interconnected and the sign and magnitude of the hinge moments of the individual surfaces become of considerable importance as the entire moment of one surface is transmitted to the stick as soon as the stick is moved from neutral. Another important point in regard to control devices of this type is that when the control column is carried through neutral in a continuous motion, as when reversing a bank, the inertia loads set up by stopping one surface and setting the other in motion are transmitted through the stick and are a source of considerable annoyance to the pilot.

Of the lateral control devices originally tested the upper-surface ailerons appeared to offer the greatest promise of being developed into a satisfactory control system, as they had about the same characteristics as conventional ailerons with the exception of the required stick force. The retractable ailerons were developed from the upper-surface ailerons through an attempt to obtain the same rolling and yawing action with decreased stick forces. In effect, the upper-surface ailerons are flap-type spoilers located at the trailing edge of the wing instead of ahead of the maximum ordinate as is usual with spoilers. Experience has indicated that flap-type spoilers are interchangeable with retractable spoilers as far as the rolling and yawing actions are involved, and that retractable spoilers have very low hinge moments (reference 2). The retractable ailerons are, in effect, retractable spoilers and were therefore substituted for the upper-surface ailerons. In the actual installation it was necessary to install the retractable ailerons slightly ahead of the upper-surface ailerons to obtain sufficient internal space into which to retract the ailerons. As a result the retractable ailerons had one-tenth second lag; whereas the upper-surface ailerons had none. The fact that the pilots did not notice this lag indicates that it is not absolutely necessary that the lag be zero, as was previously thought. On the other hand, the lag should not be much over one-tenth second as the tests of reference 2 have already shown that a lag of only one-quarter second is very objectionable. Mechanically, the difficulty of having the inertia loads of the surfaces reacting through the stick when the control

stick is carried through neutral was alleviated by using a differential movement with the retractable ailerons, one aileron retracting into the wing as the other moves out from the wing surface.

As previously mentioned, the only characteristics of the retractable ailerons to which the pilots reacted unfavorably were the very light stick forces and the lack of control feel. The principal aerodynamic forces on the ailerons are normal to their surfaces and consequently the resultant force passes through the center of curvature. As the hinge axis was made coincident with the center of curvature in the present installation to keep the size of the slot required in the wing surface to a minimum, the ailerons produced practically no aerodynamic moment. Only the moment resulting from the weight of the surfaces could be felt when moving the control stick. Consequently, the control feel was independent of air speed and, in fact, was the same in flight as on the ground. Two means of introducing aerodynamic hinge moments that will vary with deflection and thus improve the aerodynamic feel of the device have been suggested. One is to offset the hinge axis from the center of curvature so that the resultant force will pass above the hinge. The other is to utilize a wind vane either attached or auxiliary to the control surface. Both these methods require development. The use of a hinge axis not coincident with the center of curvature of the plate necessitates a wider slot in the wing. The minimum offset of the hinge axis should be determined so that the narrowest slot can be used. The shape, size, and disposition of the wind vane should also be investigated.

Quite aside from their control action, the retractable ailerons have several disadvantages. The external hinge must add an appreciable amount to the wing drag. The slot in the wing surface may also contribute to the drag, although the slot is possibly so far aft on the wing surface as to be in a region of turbulent flow and not appreciably affect the drag. The possibility of eliminating the external hinges by operating the ailerons on a track, as is conventional with leading-edge slots, was considered. With the ailerons of the chord used in the present installation this arrangement would be difficult, space not being available for the necessary guides. It may be possible, however, in other installations with ailerons of greater span and less chord to use some such operating system. The structural problems arising from the slotted wing surface are not serious. It is necessary to weatherproof the compartments into which the ailerons retract. The trailing edge of the wing in the present installation is supported on a false spar mounted between the flap-hinge brackets. The retractable ailerons have the advantage of being adaptable for use with any type of full-span flap.

The narrow-chord ailerons proved to be the most satisfactory lateral control tested for use with full-span flaps and require no further development. The flap for use with them, however, must be adapted to the purpose. It should be appreciated that the narrowness of the chord has to be compensated for by greater deflections. In general, the maximum rolling moment that can be obtained with the aileron set at any angle decreases with the aileron chord. Thus the adaptability of the lateral control system is limited by the amount of aileron control required, the size of the aileron being limited to the area aft of the flap.

A check of the flight data on rolling-moment coefficients for the different control devices against data on corresponding control arrangements given in reference 1 indicates that correcting the flight data to zero rate of roll does not eliminate all the differences between the flight and wind-tunnel test conditions and that the data from the two types of tests are not comparable. The flight tests give lower rolling-moment coefficients than do the tunnel tests. The rolling criterion is, of course, affected in the same manner as the rolling-moment coefficient. Consequently, although the desirable value of the rolling criterion, 0.075, used in reference 1 may be satisfactory for wind-tunnel work, it probably should be revised downward when flight data are considered. The control with the three devices tested was considered satisfactory within the range of the instrument tests although, with the standard ailerons, the rolling criterion had a value as low as 0.020 at slow speed.

From the experience gained with flaps during the tests, some points concerning their operation have been noted. Extended, both flaps were aerodynamically the same, the principal difference between them being in the mechanism to retract them and the manner in which they were retracted. No tests were made in flight to obtain the aerodynamic characteristics of the flaps, the plain split flap having already been tested on the airplane in the full-scale tunnel. (See reference 5.) Neither flap installation was entirely satisfactory in flight because of the high operating forces required and the resulting length of time required to extend or retract them. A condition of apparent general instability at low speeds was also noted with the flaps down for which no satisfactory explanation can be given at this time.

Experience with these flaps having indicated the necessity for the development of a quickly operated flap, such a development has been started. A balanced split flap with low hinge moments is now undergoing flight tests in combination with the retractable ailerons.

CONCLUSIONS

1. The controllable auxiliary airfoils were unsatisfactory as a means of obtaining lateral control and, because of their lag characteristics, offer little promise of development.

2. The external ailerons with down-only movement were also unsatisfactory because of their lag. With up-only movement they were the only device tested that gave any control above the stall. In the normal-flight range, however, they are in need of further development because of the relatively poor effectiveness and the irregular variation of hinge moments. It is desirable that this development be attempted because external ailerons give control beyond the stall, and the results may possibly show a method of improving the lateral stability in this flight range.

3. The upper-surface aileron had rolling and yawing characteristics similar to those of conventional ailerons but required an excessively large operating force.

4. The retractable aileron and the narrow-chord aileron are both satisfactory for use with full-span flaps. The retractable aileron has greater adaptability than the narrow-chord aileron but necessitates a more complicated installation. Neither device gives control above the stall.

5. The tests have shown the desirability for developing a flap that can be operated easily and quickly.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., *November 7, 1934.*

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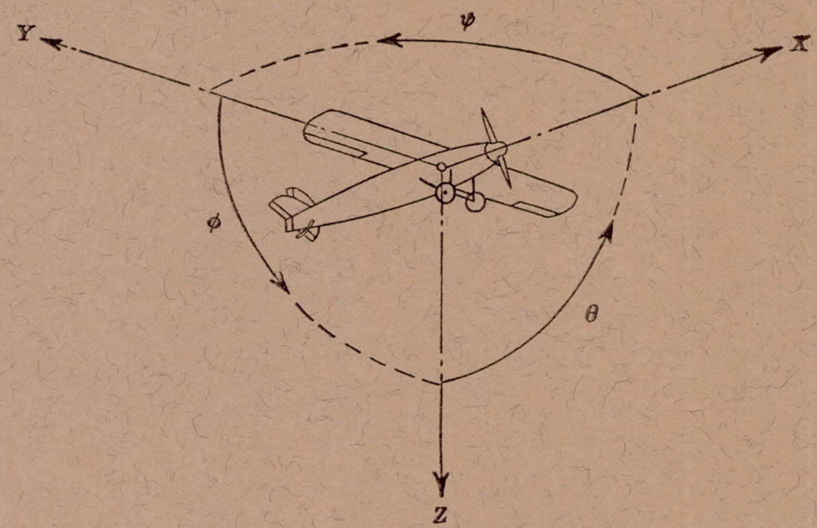
U. S. GOVERNMENT PRINTING OFFICE: 1935



Positive directions of axes and angles (forces and moments) are shown by arrows

Axis		Force (parallel to axis) symbol	Moment about axis			Angle		Velocities	
Designation	Symbol		Designation	Symbol	Positive direction	Designation	Symbol	Linear (component along axis)	Angular
Longitudinal	X	X	Rolling	L	$Y \longrightarrow Z$	Roll	ϕ	u	p
Lateral	Y	Y	Pitching	M	$Z \longrightarrow X$	Pitch	θ	v	q
Normal	Z	Z	Yawing	N	$X \longrightarrow Y$	Yaw	ψ	w	r

Absolute coefficients of moment

$C_l = \frac{L}{qbS}$ (rolling) $C_m = \frac{M}{qcS}$ (pitching) $C_n = \frac{N}{qbS}$ (yawing)

Angle of set of control surface (relative to neutral position), δ. (Indicate surface by proper subscript.)

4. PROPELLER SYMBOLS

D, Diameter

p, Geometric pitch

p/D, Pitch ratio

V', Inflow velocity

V_s, Slipstream velocity

T, Thrust, absolute coefficient $C_T = \frac{T}{\rho n^2 D^4}$

Q, Torque, absolute coefficient $C_Q = \frac{Q}{\rho n^2 D^5}$

P, Power, absolute coefficient $C_P = \frac{P}{\rho n^3 D^5}$

C_s, Speed-power coefficient $= \sqrt[5]{\frac{\rho V^5}{P n^2}}$

η, Efficiency

n, Revolutions per second, r.p.s.

Φ, Effective helix angle $= \tan^{-1}\left(\frac{V}{2\pi r n}\right)$

5. NUMERICAL RELATIONS

1 hp. = 76.04 kg-m/s = 550 ft-lb./sec.

1 metric horsepower = 1.0132 hp.

1 m.p.h. = 0.4470 m.p.s.

1 m.p.s. = 2.2369 m.p.h

1 lb. = 0.4536 kg.

1 kg = 2.2046 lb.

1 mi. = 1,609.35 m = 5,280 ft.

1 m = 3.2808 ft.